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(54) **METHODS FOR FORMING AND INTEGRATED CIRCUIT STRUCTURES CONTAINING RUTHENIUM CONTAINING LAYERS**

HERSTELLUNGSMETHODE UND INTEGRIERTE SCHALTUNGSSTRUKTUR MIT RUTHENIUMHALTIGEN SCHICHTEN

PROCEDES DE FABRICATION ET STRUCTURES DE CIRCUITS INTEGRES CONTENANT DES COUCHES A TENEUR EN RUTHENIUM

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(73) Proprietor: **MOSAID Technologies Incorporated**
Ottawa, ON K2K 2X1 (CA)

(72) Inventors:
- **AGARWAL, Vishnu, K.**
  Boise, ID 83706 (US)
- **DERDERIAN, Garo**
  Boise, ID 83716 (US)
- **SANDHU, Gurtej, S.**
  Boise, ID 83706 (US)
- **LI, Weimin, M.**
  Boise, ID 83713 (US)
- **VISOKAY, Mark**
  Richardson, TX 75082 (US)
- **BASCERI, Cem**
  Boise, ID 83706 (US)
- **YANG, Sam**
  Wappingers Falls, NY 12590 (US)

(74) Representative: **Nederlandsch Octrooibureau**
P.O. Box 29720
2502 LS The Hague (NL)

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Description

Field

[0001] The invention pertains to semiconductor devices and the fabrication thereof, and particularly to ruthenium-containing electrically conductive layers and the formation and use thereof.

Background

[0002] A capacitor generally includes two electrical conductors in close proximity to, but separated from, each other. The two conductors form the "plates" of the capacitor, and may be separated by a dielectric material. When a voltage is applied across the plates of a capacitor, electrical charge accumulates on the plates. If the plates are electrically isolated essentially immediately after a voltage is applied, the accumulated charge may be stored on the plates, thus "storing" the applied voltage difference.

[0003] The fabrication of integrated circuits involves the formation of electrically conductive layers for use as various circuit components, including for use as capacitor plates. Memory circuits, such as DRAMs and the like, use electrically conductive layers to form the opposing plates of storage cell capacitors.

[0004] The drive for higher-performance, lower-cost integrated circuits dictates ever-decreasing area for individual circuit features, including storage capacitors. Since capacitance of a capacitor (the amount of charge that can be stored as a function of applied voltage) generally varies with the area of capacitor plates, as the circuit area occupied by the storage capacitor decreases, it is desirable to take steps to preserve or increase capacitance despite the smaller occupied area, so that circuit function is not compromised.

[0005] Various steps may be taken to increase or preserve capacitance without increasing the occupied area. For example, material(s) having higher dielectric constant may be used between the capacitor plates. Further, the plate surfaces may be roughened to increase the effective surface area of the plates without increasing the area occupied by he capacitor.

[0006] One method for providing a roughened surface for a plate of a storage cell capacitor is to form the plate of hemispherical grain polysilicon (HSG), possibly with an overlying metal layer. The hemispherical grains of HSG enhance the surface area of the plate without increasing its occupied area.

[0007] HSG presents difficulties in fabrication, however, because of the formation of silicon dioxide on and near the HSG. A silicon dioxide layer may form on the HSG, particularly during deposition of the capacitor's dielectric layer. Even with an intervening metal layer present, oxygen from the deposition of the dielectric layer can diffuse through the metal layer, forming silicon dioxide at the polysilicon surface. Silicon diffusion through the metal layer may also produce a silicon dioxide layer between the metal and the dielectric layers.

[0008] Silicon dioxide between the metal layer and the HSG can degrade the electrical contact to the metal capacitor plate surface. Silicon dioxide between the metal layer and the dielectric layer can decrease the capacitance of the resulting capacitor.

[0009] To attempt to avoid these negative effects caused by formation of silicon dioxide, a diffusion barrier layer may be employed between the HSG and the metal layer. However, in the typical capacitor geometry, the greater the total number of layers, the larger the required minimum area occupied by the capacitor. Further, the upper surface of each additional layer deposited tends to be smoother than the underlying surface, reducing the increased surface area provided by an underlying rough layer.

[0010] While high-dielectric constant materials are known, many of these advantageous materials are formed with processes that are incompatible with other materials needed to form capacitors. For example, processes needed to form a particular dielectric layer can oxidize or otherwise impair the properties of the electrode layer on which the dielectric layer is to be formed. These processes can be incompatible because of the necessary process temperatures or process ambients.

[0011] For these reasons, improved materials and methods are needed for forming conducting layers, insulating layers, and capacitors using such layers.

[0012] The method of forming an enhanced-surface-area electrically conductive structure, considered herein, is a method of the kind comprising steps of:

> providing a layer containing ruthenium oxide; and
> converting at least a portion of the ruthenium oxide layer to ruthenium so as to produce a ruthenium-containing layer having a rough surface.

[0013] Examples of methods of this kind have been disclosed in each of the following two articles:

> "Annealing of RuO2 and Ru Bottom Electrodes and Its Effects on the Electrical Properties of (Ba, Sr) Ti O3 in Thin Films" by Ahn, J-H, et al., Japanese Journal of Applied Physics, Japan Society of Applied Physics, Tokyo, JP, vol. 37 no. 1, part 1, January 1998 (1998-01), pages 284 -289, X 001032003 ISSN: 0021-4922; and
> " Thermal Stability of RuO2 Thin Films and Effects of Annealing Ambient on Their Production Process", by Kaga Y et al., Japanese Journal of Applied Physics, Tokyo, JP, vol. 38, no. 6A, June 1999, pages 3689-3692, XP000883344.

[0014] It is also known that the annealing at high temperatures is effective to roughen the surface of a bottom RuO2 electrode. More than 10 nm rms reference has reported. Further details of this can be found in the fol-

lowing article:

"Effect of RuOx Bottom Electrode Annealing Temperature on Sol-Gel Derived PZT Capacitors" Integrated Ferroelectrics, New York, NY, US, vol. 10, 20 March 1995 (1995-03-20), pages 309-318, XP000770853 ISSN: 1058-4587.

In the present invention, a method of manufacturing a capacitor comprising enhanced-surface-area (rough-surfaced) ruthenium-containing electrically conductive layers is provided according to claim 1.

Summary

[0015] The present invention provides improved conductive layers, dielectric layers, capacitors, methods for forming such layers, and capacitors using the layers.

[0016] In an example, enhanced-surface-area (rough-surfaced) ruthenium containing electrically conductive layers are provided. These layers are compatible with high-dielectric-constant materials and are useful in the formation of integrated circuits, particularly for plates of storage capacitors in memory cells.

[0017] In one approach, the enhanced-surface-area electrically conductive layer may be formed by first forming a ruthenium oxide containing film or layer. The layer may be stoichiometric or non-stoichiometric, and may be amorphous or may have both ruthenium (Ru) and ruthenium oxide (RuO_2) phases and may include other materials. The film may be formed, for example, by chemical vapor deposition techniques or by sputtering or any suitable techniques. The film may be formed over an underlying layer which may be electrically conductive.

[0018] The ruthenium oxide film may be processed at low pressure and high temperature-generally at pressures at least about $1.0x10^4$ Pa (75 torr) or below, desirably about $2.7x10^3$ Pa (20 torr) or below, most desirably about $6.7x10^2$ Pa (5 torr) or below-and at temperatures in the range of about 500 to 900°C desirably about 750 to about 850°C-so as to convert at least some of the ruthenium oxide to ruthenium and to yield a roughened ruthenium-containing layer with a mean grain size desirably in the range of about 10 nm (100 Angstroms) or larger.

[0019] The heating process, or anneal, is desirably performed in a non-oxidizing ambient. In an example embodiment, a nitrogen-supplying ambient or nitrogen-supplying reducing ambient may be used during the anneal. A nitrogen-supplying reducing ambient may be used to passivate the ruthenium for improved compatibility with high-dielectric-constant dielectric materials. In another alternative, a nitrogen-supplying reducing ambient may be used in a post-anneal to passivate an already roughened layer. In each case, a post-anneal in an oxidizing ambient is performed, following either the roughening anneal or the nitride-passivation anneal, as desired. This oxidizing post-anneal provides oxygen to the roughened layer to reduce the tendency of the ruthenium to scavenge oxygen during later processing.

[0020] The enhanced-surface-area layer may be formed with or without a pre-anneal, performed at a higher pressure (such as about $8.0x10^4$ Pa (600 torr)), before the low pressure, high temperature anneal.

[0021] The roughened layer of ruthenium may be used to provide an enhanced-surface-area electrically conductive layer.

[0022] In an example, the roughened layer of ruthenium may be formed on an underlying electrically conductive layer, with the roughened layer and the underlying layer together functioning as an enhanced-surface-area electrically conductive layer.

[0023] In another example, an electrically conductive layer may be formed on or over the roughened layer, with the overlying electrically conductive layer and the roughened layer constituting an enhanced-surface area electrically conductive layer.

[0024] In either case, in an example capacitor embodiment for use in an integrated circuit, the resulting enhanced-surface-area electrically conductive layer may be used to form a plate of a storage capacitor in an integrated circuit, such as in a memory cell of a DRAM or the like.

[0025] The ruthenium-containing enhanced-surface-area electrically conductive layer, particularly in the case of an anneal in nitrogen-supplying reducing ambient with an oxidizing post-anneal, has reduced tendency toward oxidation and is thus more compatible with the use of high-dielectric-constant dielectric materials, while still providing enhanced surface area. In addition, even if the ruthenium-containing layer oxidizes, it remains conductive. An additional metal layer thus may potentially be omitted from the capacitor structure, allowing smaller dimensions for capacitors with the same or even greater capacitance.

[0026] These methods, conductive and dielectric layers, and structures using the layers allow the design and fabrication of higher speed, higher density, and lower cost integrated circuits.

Brief Description of the Drawings

[0027]

FIG. 1 is a partial cross-section of layers used in a process according to one embodiment, the layers including a ruthenium oxide containing layer;

FIG. 2 is a cross-section of the layers of FIG. 1 after a low-pressure, high-temperature anneal, including a roughened layer;

FIG. 3 is a partial plan view of the layers of FIG. 2;

FIG. 4 is a cross-section similar to that of FIG. 2 but having an additional layer underlying the roughened layer.

FIG. 5 is a cross section of the layers of FIG. 2 after formation of an additional layer overlying the roughened layer.

FIG. 6 is a cross section of an enhanced-surface-area electrically conductive layer with a dielectric layer formed thereon according to one embodiment.

FIG. 7 is a cross section of the layers of FIG. 6 with an electrically conductive layer formed on the dielectric layer; and

FIGS. 8A-8B are cross-sections of two embodiments of capacitor structures that include a roughened layer.

Detailed Description

[0028] The present invention allows creation of a surface-area-enhanced ruthenium electrically conductive layer that has improved compatibility with high-dielectric-constant ("high-κ") dielectric materials as compared to hemispherical-grain polysilicon (HSG).

[0029] The surface-area-enhanced electrically conductive layer is created by heating a film or layer comprising ruthenium oxide such as the layer 12 of FIG. 1. The heating process, which may anneal the film or layer, is typically performed at low pressures of less than about $1.0x10^4$ Pa (75 torr), desirably less than about $2.6x10^3$ Pa (20 torr), and most desirably less than about $6.7x10^2$ Pa (5 torr), and at high temperatures in the range of about 500 to 900°C, desirably about 750 to 850°C. The treatment is desirably performed in a non-oxidizing ambient. The heating process may be performed in a noble ambient, nitrogen ambient, or the like, or in a reducing ambient, which may reduce the temperature required. The heating process may also be performed in an electrically neutral environment, or with plasma or glow-discharge assistance or the like, which may also reduce the temperature required. Heating under relatively low pressure converts at least a portion of the ruthenium oxide to ruthenium and produces a rough surface on the layer. Temperature and pressure are preferably selected so as to enhance the ruthenium oxide to ruthenium conversion.

[0030] The surface-area-enhanced electrically conductive layer may be formed on a supporting structure 10 shown in partial cross-section in FIG. 1. The supporting structure 10 may be any structure present in or on an integrated circuit during the fabrication thereof. In a typical example application, the supporting structure may be an electrically conductive material that will be in electrical contact with a capacitor plate formed by the surface-area-enhanced electrically conductive layer.

[0031] The ruthenium oxide layer 12 may be formed by any suitable method. Specific examples of such methods include chemical vapor deposition (CVD) or related process, or sputtering or related process, or the like. The ruthenium oxide layer may be stoichiometric ruthenium oxide (RuO_2) or non-stoichiometric ruthenium oxide (RuO_x).

[0032] If the layer 12 is formed via CVD, the deposition may be performed, for example, at pressures of $1.3x10^2$ to $2.6x10^3$ Pa (1-20 torr), desirably about $6.7x10^2$ Pa (5 torr). The oxygen may be supplied in the form of O_2 or other oxidizing gas, such as N_2O, NO, or ozone (O_3). The oxygenating gas and a ruthenium precursor, and suitable diluent gasses, if desired, maybe supplied at suitable flow rates, such as in the range of about 100-2000 sccm. Alternatively, the ruthenium precursor can be deliver by direct vaporization. Deposition may be performed for a time in the range of about 10 to 500 seconds, desirably for sufficient time and under sufficient conditions to deposit RuO_x or RuO_2 to a thickness in the range of about 10-60 nm (100 to 600 Angstroms).

[0033] The resulting ruthenium oxide layer 12 may optionally be pre-annealed, such as by rapid thermal anneal (RTA) in hydrogen or other suitable anneal environment a pressures in the range of $6.7x10^4$ to $9.3x10^4$ Pa (500 to 700 torr) and temperatures in the range of 500 to 900°C. The pre-anneal stabilizes the film, promoting crystallization of ruthenium and ruthenium oxide phases.

[0034] The ruthenium oxide layer 12, with or without a pre-anneal, is then treated at low pressure and high temperature as described above. The treatment may reduce the proportion of ruthenium oxide in the layer and increase the proportion of ruthenium. The ruthenium oxide in the ruthenium oxide layer 12 is partially or completely converted to ruthenium by the anneal, leaving an enhanced-surface-area layer 16 shown in the cross section of FIG. 2. While the enhanced-surface-area layer 16 is referred to by separate reference character for convenience herein, it should be noted that the layer 16 is formed from the layer 12, and is the same layer in that sense. FIG. 3 shows a partial plan view of the roughened ruthenium layer 16 of FIG. 2. Although the example roughened ruthenium layer 16 shown in the figures is discontinuous, this is by way of example only and continuous films may also be produced. Increased thickness of the initial layer 12 tends to produce more continuous films, as does reduced temperature and increased pressure during the anneal and reduced anneal time.

[0035] The anneal may be performed in a noble, nitrogen, or reducing ambient or the like. As an additional example embodiment, an anneal may be performed in a nitrogen-supplying reducing ambient such as such as ammonia, nitrogen, a nitrogen and hydrogen mixture, and the like. The anneal parameters may be selected such that "nitrogen-passivated" ruthenium in the form of RuN_x is formed in the layer 16, at least near the outermost surfaces thereof, passivating the layer 16.

[0036] As another example alternative, nitride passivation may be used in the form of a post-anneal in a nitrogen-supplying reducing ambient.

[0037] As yet another variation, a desirably brief post-anneal in an oxidizing ambient such as oxygen or ozone may be performed on the already roughened layer 16, to form "oxygen-passivated" ruthenium or ruthenium nitride in the outermost portions of the layer 16 (RuO_xN_y or RuO_x), in order to reduce or prevent the ruthenium from later scavenging oxygen from a nearby dielectric material. The oxidizing post-anneal may optionally follow a nitride passivation post-anneal.

[0038] As indicated in FIG. 2, the roughened ruthenium layer 16, together with the supporting structure 10 if electrically conductive, may together constitute an enhanced-surface-area electrically conductive layer 26 compatible with high-dielectric-constant dielectric materials.

[0039] The layer 16 produced such as described above may also be used in cooperation with other layers. This may be useful in cases where the supporting structure 10 may not be electrically conductive or may be incompatible with high-dielectric-constant dielectric materials. In the discussion and claims herein, "on" used with respect to two layers, one "on" the other, means at least some contact between the layers, while "over" means the layers are in close proximity, but possibly with one or more additional intervening layers such that contact is not required. Neither "on" nor "over" implies any directionality as used herein.

[0040] As shown, for example, in FIG. 4, a layer 22 of material may be formed over the supporting structure 10, with the roughened ruthenium layer 16 then formed on the layer 22. The layer 22 may be an electrically conductive layer to electrically connect all portions of layer 16. The layer 22 may also act as a barrier layer to prevent contact between high-dielectric-constant dielectrics, to be used for capacitor formation, and the supporting structure 10. If the layer 22 is an electrically conductive layer, layer 22 together with layer 16 constitute an enhanced-surface-area electrically conductive layer 26. Any compatible electrically conductive material may be used, such as Pt, Ir, IrO_x, Rh, $RuSi_x$, and $SrRuO_x$ and alloys thereof as well as $RuSiO_x$ and $RuSiN_x$, for example.

[0041] Alternatively, as shown for example in FIG. 5, a layer 24 of electrically conductive material may be formed conformally over the layer 16 and over the supporting structure 10. The layer 24, together with the layer 16, then constitutes an enhanced-surface-area electrically conductive layer 26. As with the layer 22, the layer 24 may function to electrically connect all portions of layer 16, and may also function as a barrier layer to prevent contact between high-dielectric-constant dielectrics and the supporting structure 10. Examples of such electrically conductive materials include the materials listed in the preceding paragraph. Ruthenium oxide is a desirable material because of compatibility with the underlying ruthenium layer 16.

[0042] As described by way of example above with reference to FIGS. 3-6, the supporting structure 10 and/or one or more layers above or below the layer 16 (or both) may be electrically conductive and may be employed as needed to obtain conductivity and other desired properties. The resulting enhanced-surface-area electrically conductive layer 26, shown by way of example in FIGS. 3, 5, and 6, is represented generically as layer 26 in FIG. 6. To form a capacitor with the enhanced-surface-area electrically conductive layer 26, a layer 28 of dielectric material, most desirably a high-dielectric-constant dielectric material (generally any dielectric with a dielectric constant of at least 9), such as tantalum pentoxide (Ta_2O_5), may be formed conformally over the enhanced-surface-area electrically conductive layer, as shown in FIG. 6. Other high-constant dielectrics may also be employed, such as barium strontium titanium oxide (Ba,Sr)TiO_3, lead zirconium titanium oxide $Pb(Zr,Ti)O_3$, and strontium bismuth tantalum oxide ($SrBi_2Ta_2O_9$), for example. The layer 28 is desirably sufficiently thin and conforming to provide an at least somewhat enhanced surface area on the surface away from the layer 26.

[0043] An electrically conductive layer 30 may then be formed conformally over the dielectric layer 28, as shown in FIG. 7. The surface of layer 30 uppermost in the figure is not shown because the layer may generally be of any thickness sufficiently thick to insure continuity of the layer and sufficiently thin to fit within the overall volume allotted to the capacitor. As shown in FIG. 7, the surface of layer 30 next to the dielectric layer 28 desirably conforms to the enhanced surface area of the dielectric layer 28, providing an enhanced surface area for the electrically conductive layer 30 as well. The two electrically conductive layers, layers 26 and 30, form the two plates of a capacitor. Both plates desirably have enhanced surface area relative to the area occupied by the capacitor.

[0044] Application of the plate structure shown in FIG. 7 to a container capacitor is illustrated in the cross-section of a container capacitor shown in FIG. 8A. The supporting structure 10 may be an electrically conductive plug of polysilicon or other electrically conductive material formed at the bottom of an opening in a dielectric material 32 such as borophosphosilicate glass (BPSG). The lower end of the plug typically electrically contacts a circuit element such as a transistor gate (not shown). At the sides of the cylindrical container, the BPSG itself functions a supporting structure for the capacitor plate structure. The relative thinness of the capacitor structure provided by the layer structure of FIG. 7 maximizes the capacitor plate surface area in the container capacitor of FIG. 8A, particularly for the inner (upper) electrode, the surface area of which decreases most rapidly with increasing thickness of the layer structure. The use of the enhanced-surface-area ruthenium electrically conductive layer thus provides improved capacitance in a given area.

[0045] Application of the plate structure shown in FIG. 7 to a stud capacitor is illustrated in the cross-section of a stud capacitor shown in FIG. 8B. The supporting structure 10 includes a plug 25 that extends from a surface 27 and the layers 26, 28, 30 are formed conformally on the plug 25.

[0046] In a specific example, ruthenium oxide was deposited on substrates of BPSG to a thickness of about 60 nm (600 Angstromas) by CVD. The ruthenium oxide layers were pre-annealed in nitrogen for one minute at 800°C and 8.0×10^4 Pa (600 torr), then annealed at 800°C in nitrogen for varying times and at varying pressures. Such a pre-anneal can be omitted.

[0047] On SEM examination, layers annealed for eight minutes at 6×10^2 Pa (4.5 torr) showed marked surface roughness with mean grain size of about 10 nm (100

Angstroms) or larger, with good uniformity over the substrate surface. Layers annealed for eight minutes at $8.0x10^3$ Pa (60 torr) showed some surface roughness with a mean grain approaching 10 nm (100 Angstroms), but with generally less roughness than at $6.0x10^2$ Pa (4.5 torr). Layers annealed for eight minutes a $8x10^4$ Pa (600 torr) showed generally still less roughness and still smaller grain sizes than at $8x10^3$ Pa (60 torr). Layers annealed for two minutes at $6.0x10^2$ Pa (4.5 torr) also showed a marked surface roughness, with possibly slightly less uniformity over the substrate surface than those annealed for eight minutes. X-ray diffraction studies of the annealed layers showed ruthenium as the primary constituent but the Ru/RuO_2 ratio varied with processing cotiditions.

[0048] Variations within the scope of the disclosure above will be apparent to those of ordinary skill in the art. For example, the enhanced-surface-area layers can be used in ferroelectric memories to improve storage capacity. The scope of coverage is accordingly defined not by the particular example embodiments and variations explicitly described above, but by the claims below.

Claims

1. A method of manufacturing a capacitor having a first electrode including an enhanced-surface-area electrically conductive structure (26), a high dielectric constant dielectric layer and a second electrode, in which the steps of forming the dielectric layer and the second electrode are preceded by subsequent steps of:

providing a layer (12) containing ruthenium oxide; and

converting at least a portion of the ruthenium oxide in the layer (12) to ruthenium by heating the layer in a reduced-pressure environment in a non-oxidizing ambient selected from one of the following ambients:

a nitrogen ambient;
a nitrogen-supplying ambient;
a nitrogen-supplying reducing ambient or other reducing ambient; or
an ammonia-containing ambient;
thereby producing a ruthenium-containing layer (16) having a roughened surface with a mean grain size of 10 nm or more;
exposing the ruthenium-containing layer (16) to a nitrogen-supplying reducing ambient and performing a post-anneal, thereby passivating the roughened surface of the ruthenium-containing layer;
exposing the ruthenium-containing layer (16) to an oxidizing ambient and performing a post-anneal, thereby providing oxygen to the roughened surface of the ruthenium-containing layer to reduce the tendency of the ruthenium-containing layer (16) to scavenge oxygen during later processing;

wherein the enhanced-surface-area electrically conductive structure (26) is selected from the following structures:

ruthenium-containing layer (16) formed on an electrically conductive supporting structure (10); or
ruthenium-containing layer (16) formed on an electrically conductive layer (22) provided on a supporting structure (10); or alternatively,
a layer (24) of electrically conductive material formed conformally over the ruthenium-containing layer (16) and over the supporting structure (10),
wherein the ruthenium-containing layer (16) may be discontinuous.

2. The method of Claim 1, wherein:

the step of providing said layer (12) containing ruthenium oxide is performed by depositing a layer (12) consisting essentially of ruthenium oxide onto a supporting structure (10); and
the step of converting comprises annealing the layer (12) in a reduced pressure environment in a non-oxidizing ambient thereby converting the ruthenium oxide to ruthenium, leaving a roughened layer (16) consisting essentially ofruthenium on the supporting structure (10).

3. The method of either preceding claim 1 or 2, wherein the step of converting by heating is performed by heating the layer (12) to at least 750°C.

4. The method of either preceding claim 1 or 2, wherein the step of converting by heating is performed by heating the layer (12) to at least 800°C.

5. The method of either preceding claim 1 or 2, wherein the step of converting by heating is performed by heating the layer (12) to at least 500°C for at least 2 minutes.

6. The method of Claim 1, wherein the step of converting is performed in a reduced-pressure environment with a pressure of 1.0×10^4 Pa (75 Torr) or less.

7. The method of Claim 1, wherein the step of converting is performed in a reduced-pressure environment with a pressure of 2.7×10^3 Pa (20 Torr) or less.

8. The method of Claim 1, wherein the step of convert-

ing is performed in a reduced-pressure environment with a pressure of 7 x 10^2 Pa (5 Torr) or less.

9. The method of any preceding claim, comprising the further step of forming a layer (24) of electrically conductive material conformally over the post-annealed ruthenium-containing layer (16), whereby the surface of the conductive material away from the post-annealed ruthenium-containing layer (16) has a textured surface generally corresponding to that of the post-annealed ruthenium-containing layer (16).

10. The method of any preceding claim, further comprising processing the layer (16) containing ruthenium oxide to define a first electrode by an etching process or by a chemical-mechanical polishing process.

11. The method according to any preceding claim, wherein the capacitor is used in an integrated circuit.

Patentansprüche

1. Verfahren eines Herstellens eines Kondensators, welcher eine erste Elektrode mit einer elektrisch leitfähigen Struktur (26) mit verbessertem Oberflächenbereich, eine dielektrische Schicht mit einer hohen dielektrischen Konstante und eine zweite Elektrode aufweist, wobei den Schritten eines Bildens der dielektrischen Schicht und der zweiten Elektrode folgende Schritte vorausgehen:

Bereitstellen einer Schicht (12), mit Rutheniumoxid; und
Umwandeln zumindest eines Teils des Rutheniumoxids in der Schicht (12) zu Ruthenium durch Erwärmen der Schicht in einer druckreduzierten Umgebung in einer nicht-oxidierenden Umgebung, ausgewählt aus einer der folgenden Umgebungen:

eine Stickstoffumgebung;
eine Stickstoff-versorgende Umgebung;
eine Stickstoff-versorgende reduzierende Umgebung oder eine andere reduzierende Umgebung; oder
eine Ammoniak-umfassende Umgebung;
wodurch eine Ruthenium-umfassende Schicht (16) erzeugt wird, welche eine aufgeraute Oberfläche mit einer mittleren Korngröße von 10 nm oder mehr aufweist;
Aussetzen der Ruthenium-umfassenden Schicht (16) einer Stickstoff-versorgenden reduzierenden Umgebung und Durchführen eines Nach-Temperns, wodurch die aufgeraute Oberfläche der Ruthenium-umfassenden Schicht passiviert wird;
Aussetzen der Ruthenium-umfassenden Schicht (16) einer oxidierender Umgebung und Durchführen eines Nach-Temperns, wodurch Sauerstoff der aufgerauten Oberfläche der Ruthenium-umfassenden Schicht bereitgestellt wird, um die Tendenz der Ruthenium-umfassenden Schicht (16), zu reduzieren, während eines späteren Behandelns Sauerstoff zu binden;

wobei die elektrisch leitfähige Struktur (26) mit verbessertem Oberflächenbereich aus den folgenden Strukturen ausgewählt ist:

einer Ruthenium-umfassenden Schicht (16), welche auf einer elektrisch leitfähigen Stützstruktur (10) gebildet ist; oder
einer Ruthenium-umfassenden Schicht (16), welche auf einer elektrisch leitfähigen Schicht (22) gebildet ist, welche auf einer Stützstruktur (10) bereitgestellt ist; oder alternativ,
einer Schicht (24) eines elektrisch leitfähigen Materials, welche konform über der Ruthenium-umfassenden Schicht (16) und über der Stützstruktur (10) gebildet ist, wobei die Ruthenium-umfassende Schicht (16) diskontinuierlich sein kann.

2. Verfahren nach Anspruch 1, wobei:

der Schritt eines Bereitstellens der Schicht (12) mit Rutheniumoxid durch ein Abscheiden einer Schicht (12), welche im Wesentlichen Rutheniumoxid umfasst, auf eine Stützstruktur (10) durchgeführt wird; und
der Schritt eines Umwandelns ein Tempern der Schicht (12) in einer druckreduzierten Umgebung in einer nicht-oxidierenden Umgebung umfasst, wodurch das Rutheniumoxid in Ruthenium umgewandelt wird, wobei eine aufgeraute Schicht (16), welche im Wesentlichen Ruthenium umfasst, auf der Stützstruktur (10) verbleibt.

3. Verfahren nach einem vorstehenden Anspruch 1 oder 2, wobei der Schritt eines Umwandelns durch Erwärmen durchgeführt wird durch Erwärmen der Schicht (12) auf zumindest 750°C.

4. Verfahren nach einem vorstehenden Anspruch 1 oder 2, wobei der Schritt eines Umwandelns durch Erwärmen durchgeführt wird durch Erwärmen der Schicht (12) auf zumindest 800°C.

5. Verfahren nach einem vorstehenden Anspruch 1 oder 2, wobei der Schritt eines Umwandelns durch Erwärmen durchgeführt wird durch Erwärmen der Schicht (12) auf zumindest 500°C für zumindest 2 Minuten.

6. Verfahren nach Anspruch 1, wobei der Schritt eines Umwandelns in einer druckreduzierten Umgebung mit einem Druck von 1,0 x 10^4 Pa (75 Torr) oder weniger durchgeführt wird.

7. Verfahren nach Anspruch 1, wobei der Schritt eines Umwandelns in einer druckreduzierten Umgebung mit einem Druck von 2,7 x 10^3 Pa (20 Torr) oder weniger durchgeführt wird.

8. Verfahren nach Anspruch 1, wobei der Schritt eines Umwandelns in einer druckreduzierten Umgebung mit einem Druck von 7 x 10^2 Pa (5 Torr) oder weniger durchgeführt wird.

9. Verfahren nach jedem vorstehenden Anspruch, mit dem weiteren Schritt eines Bildens einer Schicht (24) aus elektrisch leitfähigem Material konform über der nach-getemperten Ruthenium-umfassenden Schicht (16), wobei die Oberfläche des leitfähigen Materials weg von der nach-getemperten Ruthenium-umfassenden Schicht (16) eine texturierte Oberfläche aufweist, welche im Allgemeinen jener der nach-getemperten Ruthenium-umfassenden Schicht (16) entspricht.

10. Verfahren nach jedem vorstehenden Anspruch, weiter mit einem Behandeln der Schicht (16) mit Rutheniumoxid, um eine erste Elektrode zu definieren, durch einen Ätzprozess oder durch einen chemisch-mechanischen Polierprozess.

11. Verfahren nach jedem vorstehenden Anspruch, wobei der Kondensator in einer integrierten Schaltung verwendet wird.

Revendications

1. Procédé de fabrication d'un condensateur présentant une première électrode comprenant une structure électriquement conductrice surface spécifique-améliorée (26), une couche diélectrique de constante diélectrique élevée et une seconde électrode, dans lequel les étapes de formation de la couche diélectrique et de la seconde électrode sont précédées par les étapes suivantes :

   de fourniture d'une couche (12) contenant de l'oxyde de ruthénium ; et
   de conversion d'au moins une partie de l'oxyde de ruthénium dans la couche (12) en ruthénium par chauffage de la couche dans un environnement de pression réduite dans une atmosphère non oxydante choisie parmi une des atmosphères suivantes :

      une atmosphère d'azote ;
      une atmosphère d'introduction d'azote ;
      une atmosphère réductrice d'introduction d'azote ou une autre atmosphère réductrice ; ou
      une atmosphère contenant de l'ammoniaque ;
      produisant par-là une couche contenant du ruthénium (16) présentant une surface rendue rugueuse avec une taille moyenne de grain de 10 nm ou supérieure ;
      d'exposition de la couche contenant du ruthénium (16) à une atmosphère réductrice d'introduction d'azote et à réaliser un post-recuit, passivant par-là la surface rendue rugueuse de la couche contenant du ruthénium ;
      d'exposition de la couche contenant du ruthénium (16) à une atmosphère oxydante et à réaliser un post-recuit, fournissant par-là de l'oxygène à la surface rendue rugueuse de la couche contenant du ruthénium pour réduire la tendance de la couche contenant du ruthénium (16) à fixer l'oxygène pendant un traitement ultérieur ;

   dans lequel la structure électriquement conductrice surface spécifique-améliorée (26) est choisie parmi les structures suivantes :

      une couche contenant du ruthénium (16) formée sur une structure de support électriquement conductrice (10) ; ou
      une couche contenant du ruthénium (16) formée sur une couche électriquement conductrice (22) fournie sur une structure de support (10) ; ou sinon,
      une couche (24) de matériau électriquement conducteur formé de manière conforme sur la couche contenant du ruthénium (16) et sur la structure de support (10), dans lequel la couche contenant du ruthénium (16) peut être discontinue.

2. Procédé selon la revendication 1, dans lequel :

   l'étape de fourniture de ladite couche (12) contenant de l'oxyde de ruthénium est réalisée par dépôt d'une couche (12) essentiellement constituée d'oxyde de ruthénium sur une structure de support (10) ; et
   l'étape de conversion comprend le recuit de la couche (12) dans une environnement de pression réduite dans une atmosphère non oxydante convertissant par-là l'oxyde de ruthénium en ruthénium, laissant une couche rendue rugueuse (16) essentiellement constituée de ruthénium sur la structure de support (10).

3. Procédé selon l'une quelconque des revendications 1 ou 2 précédentes, dans lequel l'étape de conversion par chauffage est réalisée en chauffant la couche (12) à au moins 750°C.

4. Procédé selon l'une quelconque des revendications 1 ou 2 précédentes, dans lequel l'étape de conversion par chauffage est réalisée par chauffage de la couche (12) à au moins 800°C.

5. Procédé selon l'une quelconque des revendications 1 ou 2 précédentes, dans lequel l'étape de conversion par chauffage est réalisée en chauffant la couche (12) à au moins 500°C pendant au moins 2 minutes.

6. Procédé selon la revendication 1, dans lequel l'étape de conversion est réalisée dans un environnement de pression réduite avec une pression de $1,0 \times 10^4$ Pa (75 torr) ou inférieure.

7. Procédé selon la revendication 1, dans lequel l'étape de conversion est réalisée dans un environnement de pression réduite avec une pression de $2,7 \times 10^3$ Pa (20 torr) ou inférieure.

8. Procédé selon la revendication 1, dans lequel l'étape de conversion est réalisée dans un environnement de pression réduite avec une pression de 7×10^2 Pa (5 torr) ou inférieure.

9. Procédé selon l'une quelconque des revendications précédentes, comprenant l'étape supplémentaire de formation d'une couche (24) de matériau électriquement conducteur de manière conforme sur la couche contenant du ruthénium post-recuite (16), sur quoi la surface du matériau conducteur partant de la couche contenant du ruthénium post-recuite (16) présente une surface texturée correspondant en général à celle de la couche contenant du ruthénium post-recuite (16).

10. Procédé selon l'une quelconque des revendications précédentes, comprenant de plus le traitement de la couche (16) contenant de l'oxyde de ruthénium pour définir une première électrode par un procédé de gravure ou par un procédé de polissage mécano-chimique.

11. Procédé selon l'une quelconque des revendications précédentes, dans lequel le condensateur est utilisé dans un circuit intégré.

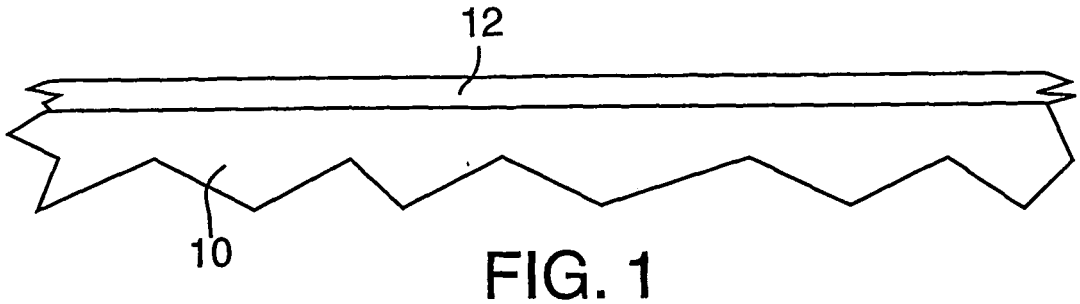

FIG. 1

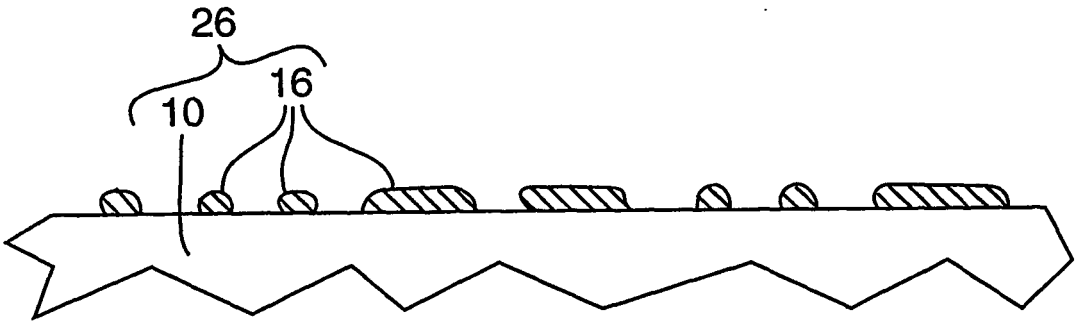

FIG. 2

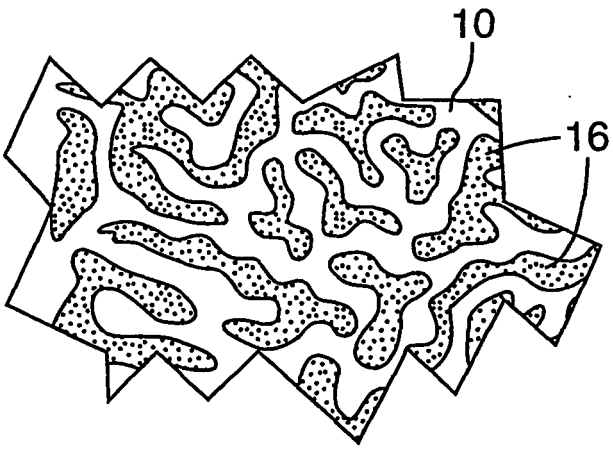

FIG. 3

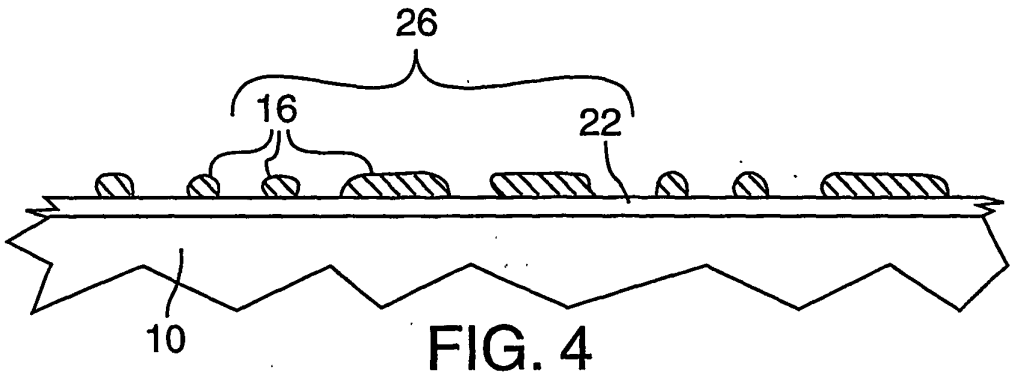

FIG. 4

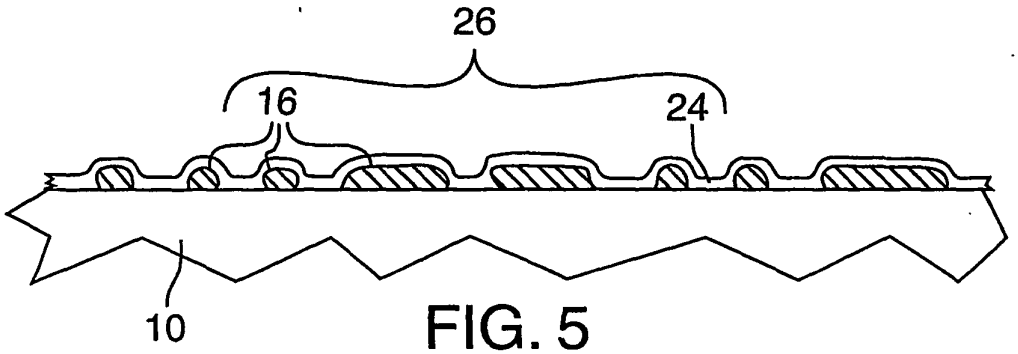

FIG. 5

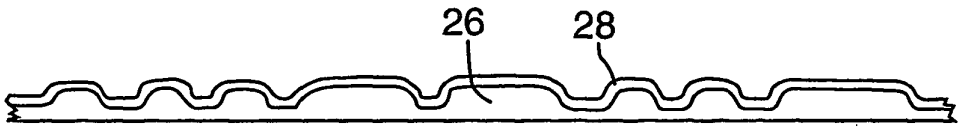

FIG. 6

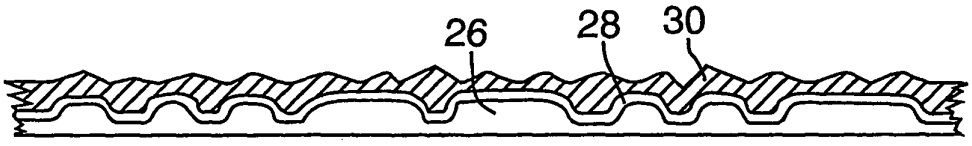

FIG. 7

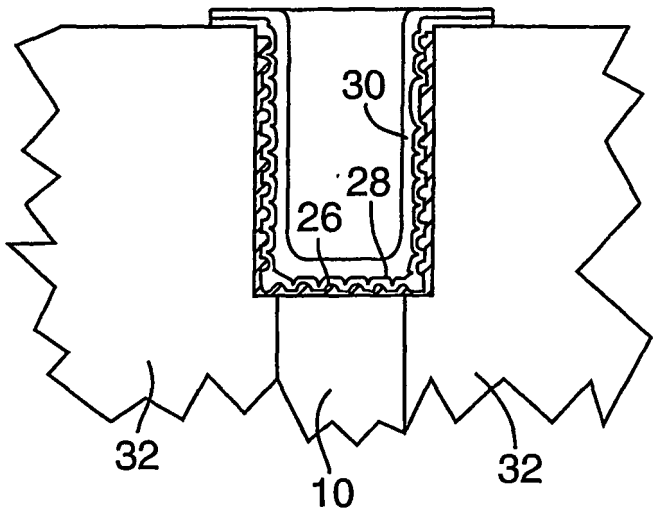

FIG. 8A

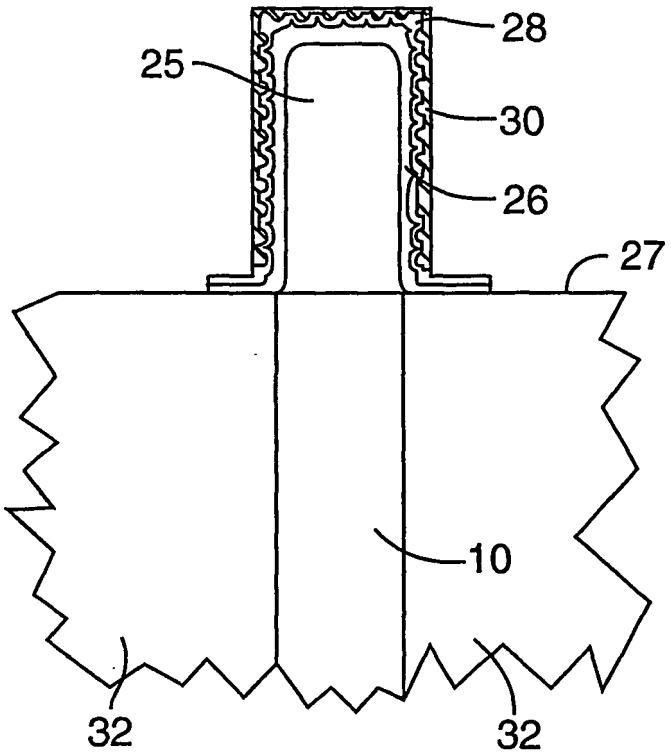

FIG. 8B

REFERENCES CITED IN THE DESCRIPTION

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- **KAGA Y et al.** Thermal Stability of RuO2 Thin Films and Effects of Annealing Ambient on Their Production Process. *Japanese Journal of Applied Physics,* June 1999, vol. 38 (6A), 3689-3692 **[0013]**
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